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AN EXAMPLE OF THE PROCESS OF SELECTING A TRAWL AND MATCHING IT TO TOWING POWER

by

W. Dickson

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
ROME, 1968

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MFS Editions provisoires des « Manuels FAO de science halieutique ».

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AN EXAMPLE OF THE PROCESS OF SELECTING A TRAWL AND MATCHING IT TO TOWING POWER

by

W. Dickson

Fishing Operations-Branch

Fishery Resources and Exploitation Division

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, July 1968

PREPARATION OF THIS TECHNICAL PAPER

This document has been prepared because the problem of how to match trawl resistance to the towing power of a trawler is one that is frequently put to FAO, either by questions from institutes in member countries, or in connection with field programs executed by the organization in the field of fisheries. It usually recurs in some specific context inasmuch as the trawl, as well as having to match the power of a given trawler, is also required to work in a certain area for certain species. The document is therefore also concerned with showing the process of selecting the characteristics of a trawl for a given fishery.

Distribution

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FAO Regional Fisheries Officers
UNDP Field Experts (FR)
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"Current Bibliography" entry

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An example of the process of selecting a trawl and matching it to towing power

Thrust at trawling speed. Net drag. Otterboard size. Net spread. Selection of net.

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Editorial Note

The calculations in this document are made in ft, lb, s, units. At some future date, along with any revisions that may be necessary, the document will be re-issued with calculations done in the m.k.s. system.

In the meantime for those who habitually work in the m.k.s. system the following conversion table may be used:

Foot, Pound, Second, System	Metre, Kilogram, Second, (m.k.s.) System
1 in (1/12 ft)	0.0254 m
1 ft	0.305 m
1 yd (3 ft)	0.915 m
1 fm (6 ft)	1.83 m
1 lb	0.454 kg
1 long ton (2240 lb)	1016 kg (1.016 metric ton)
1 hp (550 ft lb/s)	76.16 m.kg/s
	1.015 metric hp (75 m.kg/s)
acceleration due to gravity 32.2 ft/s^2	9.81 m/s^2
density of water 62.5 lb/ft^3	1000 kg/m^3
density of sea water 64 lb/ft^3	1025 kg/m^3
torque 1 lb ft	0.138 kg.m
runnage 1 yd/lb	2.02 m/kg
1 knot (6080 ft/hr)	0.515 m/s

AN EXAMPLE OF THE PROCESS OF SELECTING A TRAWL AND MATCHING IT TO TOWING POWER

Introduction

How to choose the size of net and otterboards that will match the towing power of a trawler is a problem that keeps recurring. It arose for us in connection with the small stern trawlers (33.4m, 110ft) which Yugoslavia is building for the Ceylon Fisheries Corporation to take part in the Wadge Bank trawl fishery. When the first of these small stern trawlers M.T. 'Gandara' commenced operations in late 1964 it was found that she was unable to tow at the same speed as the steam trawlers 'Braconglen' and 'Maple Leaf' (42.5m, 140ft) had done. The question then put to FAO was what size of gear could the small stern trawlers be expected to tow? This is a straight engineering problem. The corollary questions of what would be an adequate towing speed and what type of net should be used are mixed questions involving knowledge of engineering, fish behaviour and the nature of the ground to be worked.

Summary of approach

Where, as on the Wadge Bank, there has been fishing before, something can be learned from the literature available describing the nature of the ground, the fish species caught, the vessels that have operated there and the gear they have used. After reviewing the literature it may be possible to arrive at some general conclusions about what sort of gear would be an improvement on what had been used in the past and what would be an adequate towing speed, this last depending not only on fish behaviour but also on the weather and currents to be encountered.

The first step in calculation is to determine the maximum torque that the engine will produce at the propeller and from a knowledge of the propeller dimensions to derive what thrust the propeller will produce at towing speed without exceeding the maximum permissible torque. Trawl drag can then be matched to the available thrust.

From a knowledge of the drag resistance of some prototype trawl gear it is possible by the use of scaling equations to arrive at the otter board, twine and net size for the new trawl.

The new trawl gear is then specified in more detail and from considerations of its geometry in the fishing position, and of its design, the resistance first of the trawl itself and then of the whole gear is calculated.

The Wadge Bank trawl fishery

The bank is an area at the south end of India and to the west of Ceylon. The bulk of it ranges from 20 to 50 fathoms in depth and the bottom is coarse yellow sand overlying flat rock which sometimes comes to the surface, with here and there a few muddy patches. There are many sea fans (gorgonids) on the bank. Trawling commenced there in 1907, re-started in 1920 and, with only a brief gap, has continued ever since (Mendis 1965). Two oilfired steam trawlers, 'Breconglen' and 'Maple Leaf' (140 ft and with 650 indicating horse-power engines) worked this bank from 1951 onwards, and 'Maple Leaf' is still working it. Good records of the trawlers' landings have been kept. They towed a Standard Granton trawl with an 80 ft headrope and 120 ft groundrope using 10 ft by 4 ft 6 in. otter boards. Such a trawl was well matched to the power of the steam engines turning a large propeller at low rpm (probably about 80 rpm). It has not been found necessary to use heavy iron bobbins, a rope rounded groundrope being sufficient, though on the rougher edges of the bank it may be worthwhile to try light rubber bobbins. The catching rate on the bank has been at about

the same level as the waters round Bombay and on the west coast of Scotland, to mention two widely separated areas. Average catching rate by these trawlers over the years 1956 to 1963, was about 600 lb per hour's fishing. It is a feature of fishing on the bank that the haul-to-haul variation in catch rate is not large.

Fishing falls into two periods; the NE monsoon lasting from November to April and the SW monsoon from May to October. During the NE monsoon and inter-monsoon periods, only resident species are on the bank and catches at that time average about 400 lbs per hour's fishing by the steam trawlers. The residents are mainly sea bream, grouper and snapper with some shark, skate and rays. During the SW monsoon migrant species move onto the bank. These are mainly carangids such as kingfish, but also species of catfish which are less valuable. During this period catches increase to around 800 lb/hr. For the carangids, at least, there could be an advantage in having increased headline height. It did not seem that catches rose to such a level that special measures had to be adopted to bring them aboard, i.e. no specially strong codend, lengthy funnel in the net or specially strong lifting tackle appeared to be required.

Fish species

The following is a list of the principal fish species with their maximum size (Munro 1955) (the plate numbers are also given for easy reference in Munro's book) and more or less in order of their importance in the fishery (Sivalingam and Medcof 1955):

Residents

Sea Bream	Lethrinus nebulosus	(462)	76 cm (30 in)
Rock Cod	Epinephelus indulosis	(300)	38 cm (15 in)
Red Snapper	Lutianus dodecanthus	(397)	48 cm (19 in)
Blue Spotted Snapper	Lutianus revulatus	(385)	61 cm (24 in)
Painted Grunt	Plectorhynchus pictus	(436)	46 cm (18 in)
Sharks, Skates and Rays			

Migrants

Dusky Trevally	Caranx chrysophrys	(351)	36 cm (14 in)
Black-Tailed Trevally	Caranx carangus	(362)	41 cm (16 in)
Malabar Trevally	Caranx malabaricus	(352)	38 cm (15 in)

Quite a lot of the catch is comprised of sizeable fish, but the codend meshsize used has been 65 mm stretched mesh so that also quite important in the catch are small fish of the resident species, defined as those below 30 cm.

Notes on fish behaviour

It appears that during the NE monsoon, there is a general tendency for catches to be heavier at night, while during the SW monsoon the daytime catches tend to be greater. It also seems that "dark water" appears on the banks from time to time and that fishing in this is usually better than in water of high transparency.

This is not very much information on which to rationally alter the design of a net. It is not, however, out of line with what has been observed elsewhere and could be interpreted in the following way:

1. In conditions of good visibility (clear water and daylight) the demersal resident species either see better to avoid the trawl altogether or once in it, any but the largest can better escape through the 5½ in. mesh, which in the Standard Granton trawl extends right back into belly and batings, only thereafter reducing in steps towards the 65 mm codend.

   It is to help clarify such postulation that the size composition of the principal species in the catch should be measured by day and by night.

   To reduce these possibilities of avoidance or escape the proposed net will be increased somewhat (about 50%) in headline height and assuming the smaller fish to be of worthwhile importance, the meshsize in square and batings will be reduced.

   There is no reason at this stage to suggest altering the codend mesh-size.

2. When the more pelagic carangids come onto the grounds they may, as many pelagic fish do, seek closer to the bottom by daylight, rising as the light intensity falls by night. For these rather fast swimming fish a net of rather higher headline height than the Granton trawl seems desirable. It may be that a different net should be used at this season, something of the lightweight high-opening split wing style. In the meantime, however, only one net will be considered, but as already mentioned a modest increase in headline height will be one of its features.

The gear

The net chosen as the basis for design is a well tried one, used by the trawlers of Granton (Scotland). It has some rather different features from the Standard Granton trawl which trawlers from that port stopped using in the 1930s. In particular the meshes in the roof of the net are smaller to retain fish about 30 cm length. It is also chosen because the square, being shorter, gives the net greater possibility of improved headline height and spread.

It has been found good practice to make the belly and lower wings in heavier nylon twine than the roof of a net, particularly as in this case where the roof is in smaller mesh.

Details of the net and rigging are given in Fig. 9. Note that at this stage its overall size and the diameter of its twines have yet to be calculated. Certain improved features have been introduced. Height at the wing ends is given by the top wings rather than the lower wings. This is a feature of some Russian trawls; it agrees better with the fishing shape assumed by a trawl and gives the possibility of making in heavier twine that part of the trawl most likely to be damaged while making more of the net in lighter twine for reduced resistance. The mesh sizes are chosen so that the net can be cut out from machine made netting and easily joined. The belly is not made in a series of steps of different mesh sizes joined mesh for mesh as used to be the case in hand braided nets. To give headline height the three wire system is adopted with moderately long spreading wires. The wing and triangular extensions are adopted to flatten the wing and distribute the tension caused by the third wire, which tends to cause distortion of the net when attached to the selvedge in the common fashion.

There are no special groundrope requirements, a rope rounded groundrope having proved adequate in the past. There remains the possibility of using rubber bobbins to try rougher areas of the bank.

Because the bank is mostly firm sand the North European type of heavy otter boards have proved adequate enough in the past but a pair of lighter doors with wide keel plates were obtained so that areas of softer ground could be worked.

Torque available

Engine makers data showing the torque available over the speed range of the engine might be obtained, but it may be taken that engine torque which is dependent on the mean effective pressure in the cylinders is fairly constant over the working range. This available torque sets a ceiling on the rpm at which the propeller can be turned. The ceiling is not, however, a level one and it varies with the amount of constraint on the ship. The ship may be running free, when it has only its own resistance to overcome, or it may be subject to varying degrees of constraint such as punching through a head sea, towing a light trawl gear, towing a heavy trawl gear or, in the extreme case, the ship constrained to a stop. Within the limits set by the available torque, the engine will develop its maximum revolutions when the ship is running free, and its least when the ship is tied at bollard. On the other hand when all the propeller thrust is being used to drive the ship at full speed there is no thrust available for towing, and when the ship is tied to a bollard the pull in the line (bollard pull) is greatest. The propeller gives its greatest thrust at bollard at the cost of having its greatest torque there also. Bollard pull, if it is to be measured at all, should be measured in open water clear of ground effects. It is sometimes done by tying the ship up to a big and heavily moored buoy.

The engine under discussion is rated as 420/460 hp. This is a continental rating where one horsepower equals 75 metre-kilograms per second. We may take the continuous-duty rating as 420 horsepower. Since we are concerned with what happens at the propeller end, a loss of 5% is allowed in the stern tube and since in this instance the calculations are done in British units where one horsepower equals 550 ft lbs per second, the available shaft horsepower is 393 hp. The propeller curves which are going to be used are given for fresh water and, therefore, the power has to be further reduced (Traung 1964).

$$P_D = \frac{393}{1.025} = 384 \text{ hp}$$

The maximum engine rpm is 375, and assuming the engine to have a flat torque characteristic in the working range, then using the formula:

$$P_D = 2\pi nQ$$

$$\text{The maximum permissible torque} = \frac{384 \times 33000}{2\pi \times 375} = 5{,}400 \text{ lb ft}$$

This sets the limit of torque which the propeller can be allowed to put onto the propeller shaft.

Propeller data

The propeller to be used is four bladed diameter D = 1610 mm = 63½" = 5.3'

pitch P = 920 mm

P/D = 0.57

Using Troost curves (van Lammeren, W.P.A., L. Troost, J.G. Koning 1948) B.4.55, $\frac{Fa}{F}$ 0.55 and $\frac{P}{D}$ = 0.6

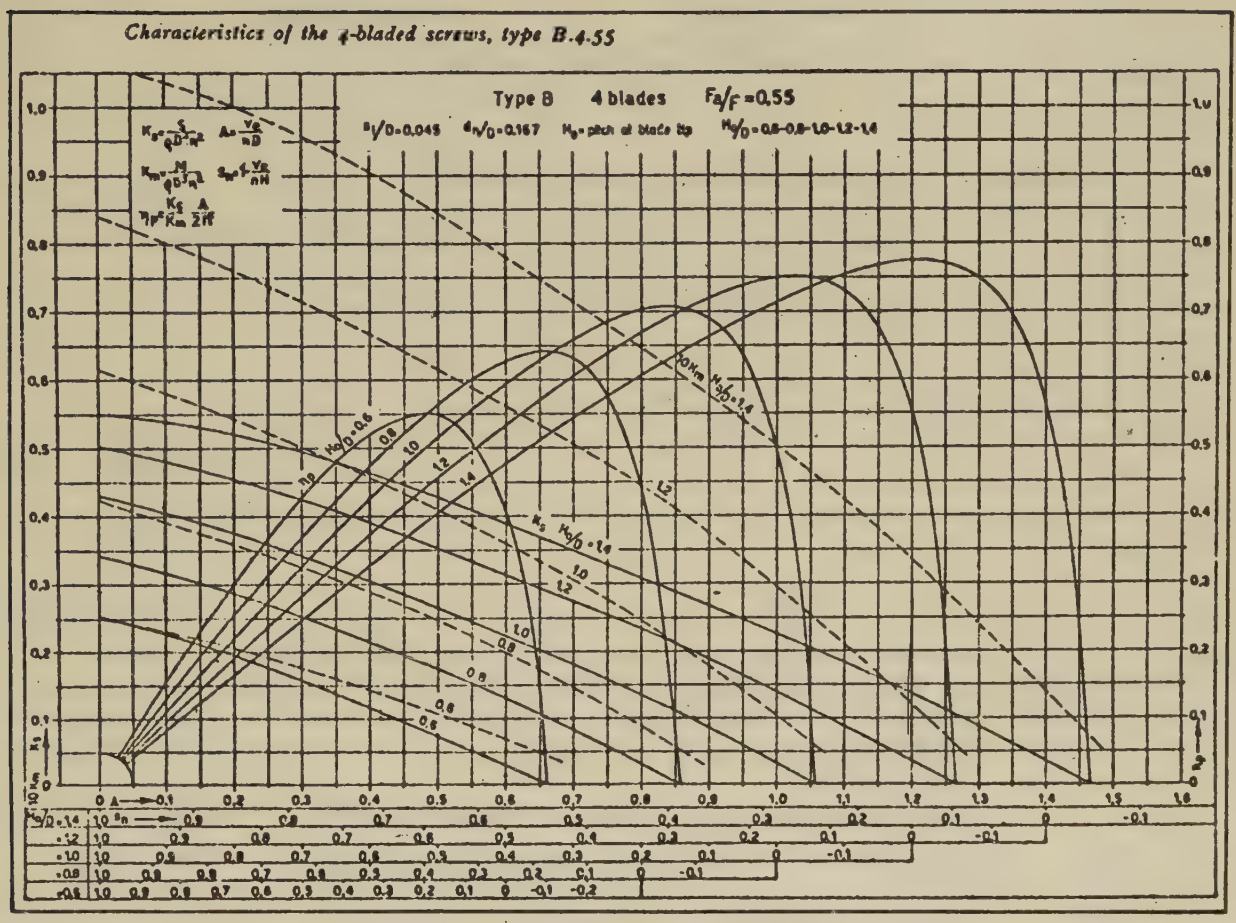


Fig. 1 Troost curves

The same symbols are used as by the FAO Fishing Vessels and Engineering Branch, and the relevant ones in the instance are:

D - Diameter

J - Speed coefficient

K_Q - Torque coefficient

K_T - Thrust coefficient

g = acceleration due to gravity

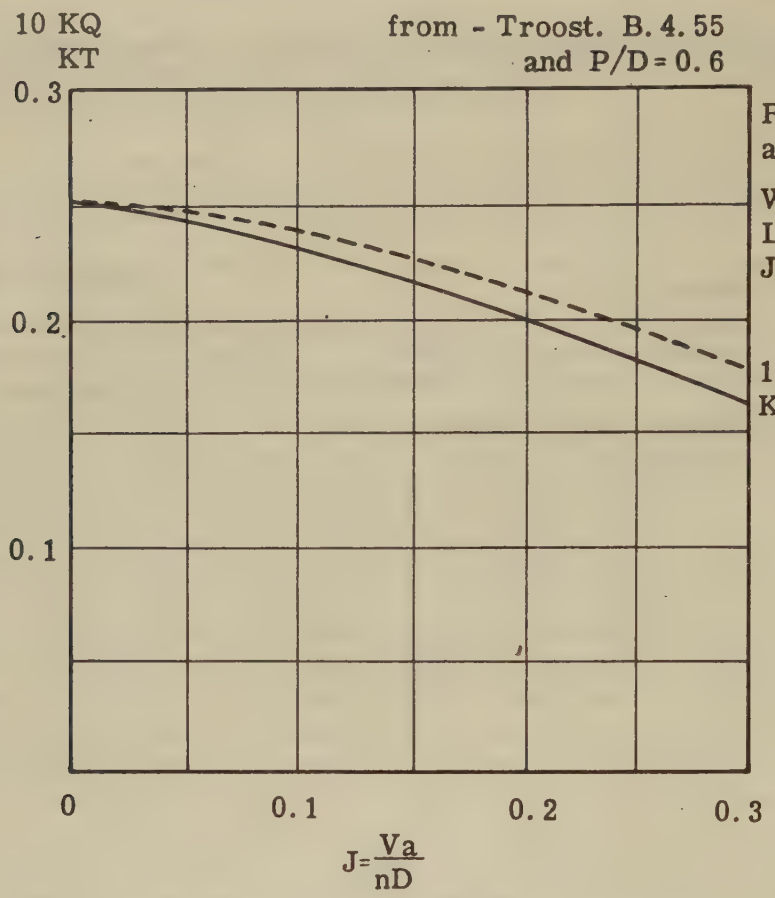


Fig. 2 Thrust and torque coefficients against speed number

N	-	Revolutions of propeller per minute
n_1	-	Revolutions of propeller per second
P	-	Pitch ρ = density of water
P_D	-	Power, delivered at propeller (old DHP)
Q	-	Torque
T	-	Thrust
V	-	Ship's speed
V_A	-	Speed of advance in knots (ship's speed - wake)
Va	-	Speed of advance in ft/sec.
w	-	Taylor wake fraction

Bollard pull

At bollard $J = \frac{Va}{n_1 D} = 0$ giving $K_Q = 0.025$, $K_T = 0.25$

$$Q = \frac{K_Q \rho D^5 n_1^2}{g}$$

$$n_1^2 = \frac{Q}{K_Q \rho D^5} = \frac{5400}{0.025 \times 1.988 \times (5.3)^5}$$

$$= 25.8 \qquad (D^5 = 4240)$$

$$\therefore \quad n_1 = 5.06 \text{ or } 304 \text{ rpm (max revs. at bollard)}$$

The thrust coefficient = 0.25 and the $T = \frac{K_t \rho n_1^2 \times D^4}{g}$ $(D^4 = 800)$

$$= .25 \times 1.988 \times 25.8 \times 800$$

$$= 4.56 \text{ ton (long tons of 2240 lbs)}$$

Thus at bollard the engine can only turn at 304 rpm without exceeding its torque limit and is only:

$\frac{304}{375}$ = 81% utilised

Wake traction

A trawler is not advancing through still water because as the hull advances it entrains water along with it. For a fuller account of this see Traung (1964), but under trawling conditions we should not be far wrong if the speed of advance of the propeller through the wake (V_a) is taken as 0.8 of the trawling speed.

Available thrust at trawling speed

As was implied when discussing the thrust which the propeller could produce, the faster the towing speed required the smaller and lighter the gear that can be towed. Towing speed should thus not be over emphasised. There are two conditions that set the minimum acceptable towing speed:

1. It must be above the minimum speed required to capture the species being sought.

2. It must be above the minimum speed required to maintain steerage way on the boat in adverse weather and tidal conditions.

It is here taken that three-and-a-half knots is an adequate towing speed.

Assume a wake fraction $w = 0.2$ where $w = \frac{V - Va}{V}$

then $Va = V(1 - w)$

$= 3.5 \times 0.8 = 2.8$ knots

$= 4.72$ ft/sec

At this point it is necessary to make a guess at which rpm the propeller will cause the engine to be overloaded. Now assume the engine can manage 325 rpm (n_1 = 5.42) at 3.5 knots.

$$J = \frac{4.72}{5.42 \times 5.3} = .164 \text{ giving } K_Q = 0.022 \; K_T \; 0.206$$

$$Q = 0.022 \times 1.988 \times 4240 \times (5.42)^3$$

$$= 5450 \text{ lb ft}$$

$$T = 0.206 \times 1.988 \times 800 \; (5.42)^2 \; /2240$$

$$= 4.34 \text{ ton}$$

This is marginally overloading the engine, since the torque of 5450 lbs.ft. is greater than the maximum available torque of 5400.

One could repeat the calculation making a new and this time better guess at a lower rpm, but it is more instructive to graph the thrust available over a range of rpm and towing speed. This is calculated in the following Table and is plotted in Figures 3 and 4 where the ceiling imposed by the maximum available torque is also shown.

Thrust v. trawling speed and torque v. trawling speed

At trawling speeds the resistance of the ship is low and it is here ignored, although it is not negligibly small.

at 300 rpm	nD = 26.5		n^2 = 25		
Speed V knots	2.5	3.0	3.5	4.0	4.5
Va	2.0	2.4	2.8	3.2	3.6
Va ft/sec	3.38	4.05	4.72	5.4	6.08
J	0.127	0.153	0.178	0.204	0.230
K_Q	0.0228	0.0222	0.0215	0.0208	0.0200
Q lb-ft	4800	4680	4540	4390	4220
K_T	0.218	0.21	0.201	0.194	0.185
T ton	3.87	3.73	3.57	3.45	3.29

at 325 rpm	nD = 28.7		n^2 = 29.4		
J	0.118	0.141	0.164	0.188	2.212
K_Q	0.0231	0.0225	0.0220	0.0213	0.0206
Q lb-ft	5720	5580	5450	5290	5100
K_T	0.221	0.213	0.206	0.199	0.190
T ton	4.61	4.44	4.30	4.15	3.96

at 350 rpm	nD = 30.9		n^2 = 34		
J	0.109	0.131	0.153	0.175	0.197
K_Q	0.0234	0.0227	0.0222	0.0216	0.0211
Q lb-ft	6700	6500	6350	6200	6050
K_T	0.224	0.217	0.210	0.202	0.196
T ton	5.4	5.22	5.05	4.86	4.72

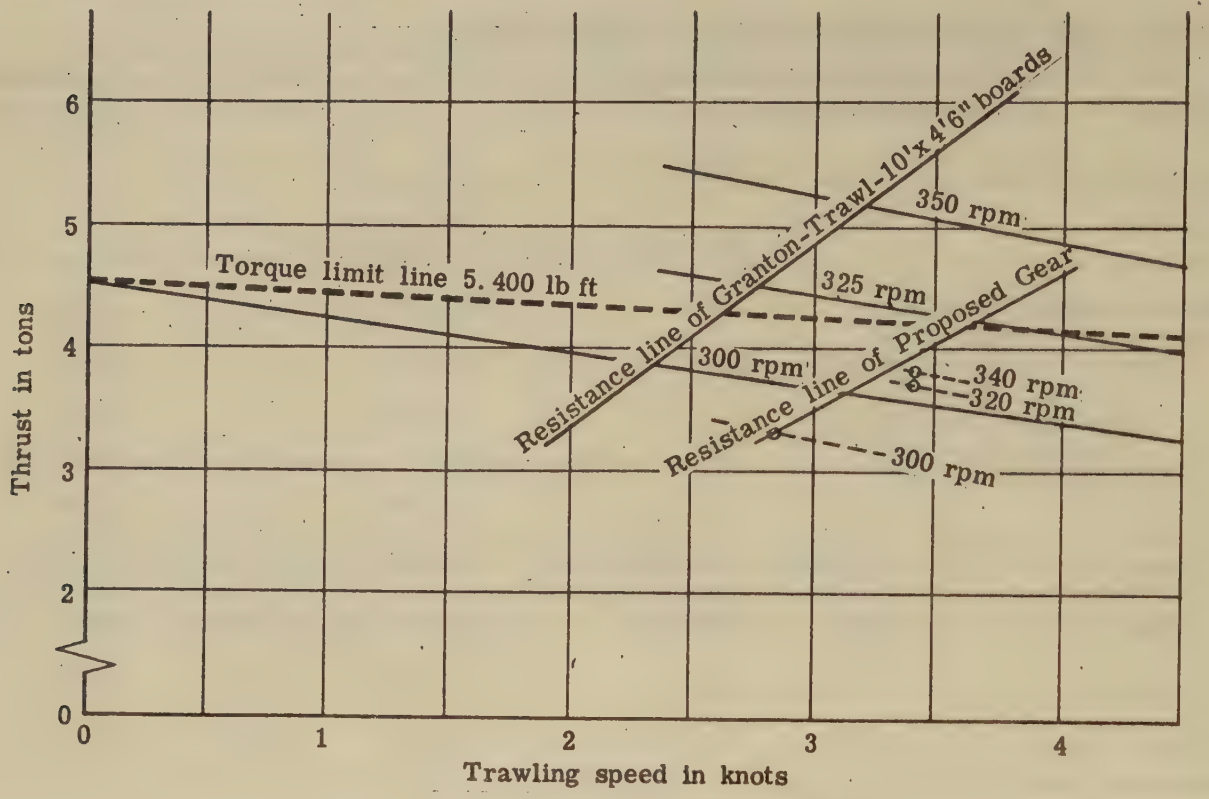


Fig. 3 Thrust at trawling speed

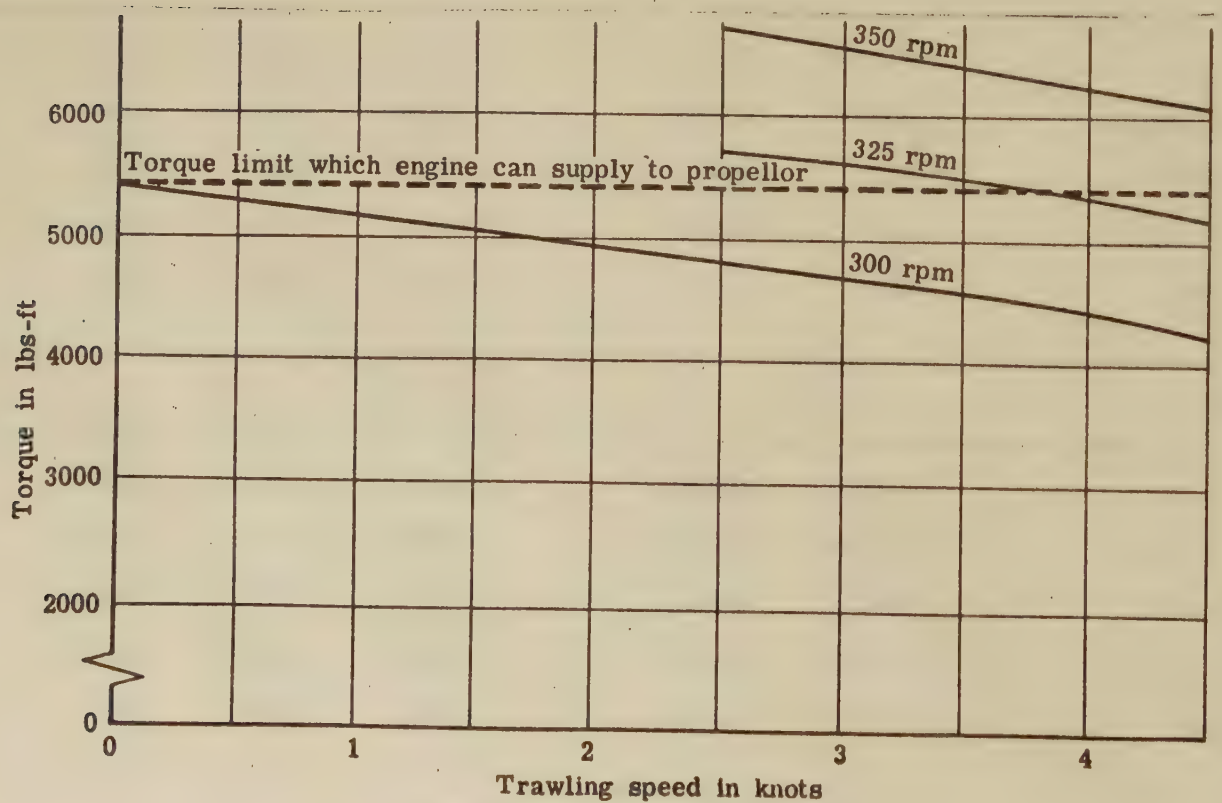


Fig. 4 Torque at trawling speed

Resistance of Granton trawl

The drag of the Granton trawl made in heavy 75 yd/lb manilla twine and spread by 11 ft x 5 ft 3 in. otterboards (58 sq.ft) has been studied (Dickson 1964) and the drag of this gear at 3½ knots may be taken as 7.3 ton. The otter boards used on the Ceylon trawlers are 10 ft x 4 ft 6 in (45 sq.ft) and the twine is 110 yd/lb manilla. The groundrope of the Granton trawl as used in Ceylon is considerably lighter than the bobbin groundrope of the Granton trawl used in the Arctic.

The figures are not available for the drag of the Granton gear as used in Ceylon, but a fair estimate can be made of what it must be. The drag of the gear is largely determined by the relative size of the otter boards and by the construction of the net.

$$\text{Drag on basis of board size} = 7.3 \times \frac{45}{58} = 5.7 \text{ ton}$$

$$\text{Drag on basis of twine diam.} = 7.3 \times \sqrt{\frac{75}{110}} = 6.0 \text{ ton}$$

It will be seen that the two estimates are close to each other implying that a net made in 75 yds to the lb manilla is matched to the 58 sq ft otter boards in much the same way as a net made in 110 yd per lb manilla is matched to 45 sq ft otter boards. The drag of a trawl is reduced approximately as the relative diameters of the twine. This is the reason why the square root of the ratio of twine runnage is used.

The drag of net appendages, bobbins, headline floats plus ground friction amounts to 0.7 ton out of the total drag of the heavy Arctic Granton trawl. For the Ceylon gear it is taken as only 0.4 ton, so that for this gear we arrive at a figure of 5.65 ton drag at 3½ knots. This resistance line is plotted on Fig.3. It is here assumed to be straight although in fact it is never quite so. Since the headline falls as speed is increased the drag of a trawl is nearer being proportioned to the first power of the speed than the second power.

From the reported views of the skipper and also from engine rpm attainable during trawling (about 315 rpm) it would appear that 2.65 knots as taken from Fig. 3, is in accordance with the capabilities of M.T. 'Gandara' to tow the 10 ft x 4 ft 6 in otter boards and Granton trawl.

Otter board, twine and net size for new trawling gear

The first thing to be considered is a suitable size of otter boards and only thereafter to consider what net should be used with them. Choice of otter board size determines not only their own drag but also quite largely determines the drag of the net according to whether it is well or poorly spread by the boards. The ratio of board size to net size and construction, as outlined above is typical and should not be departed from without good reason. It will be seen from Fig. 3 that at 3½ knots the trawling gear should have a drag of say 4.1 tons, hence board area suitable at 3½ knots = $45 \times \frac{4.1}{5.65} = 31.8$ sq.ft. A rough working rule for otter board weight is 1 kg per rated horsepower, but to allow for working in soft mud otter boards of 400 kg with a broad keel were chosen. In order to increase the efficiency of the gear a little, oval otter boards with a single slot can be used. Let it be taken that such boards will work at an angle of attack of 35°. The oval slotted board has a marginally better performance than the rectangular one (Dale and Moller 1964).

Rectangular boards aspect ratio 1:2 $C_L = 0.93$ $C_D = 0.71$

Single slotted oval boards $C_L = 1.0$ $C_D = 0.64$

Oval otter boards with a weight of 400 kg. and size 2360 mm by 1390 mm have a surface area of 28.2 sq.ft.

Thus the 28.2 sq.ft. oval board gives the same lift as a 31.4 sq.ft. rect. board

" " 28.2 " " " " " " " drag " " 25.4 " " " "

These 400 kg otter boards should then do quite well.

Net and twine size

By the use of nylon or polypropylene twine it is possible to effect a reduction in net drag without loss of strength. To match the reduced otter-board size it is necessary to reduce the twine diameter. The permissible size of twine to give the same fishing dimensions as the Granton trawl in 110 yd/lb mouth with the 45 sq. ft. otterboards is given by:

$$\frac{d_2}{d_1} = \left[\frac{\rho_1 R_1}{\rho_2 R_2}\right]^{\frac{1}{2}}$$

where d = twine diameter
ρ = sp.gr. of twine

$$\frac{32.4}{45} = \left[\frac{1.29 \times 110}{1.14 \times R}\right]^{\frac{1}{2}}$$

R = runnage of twine

R = 240 yds/lb. nylon (sp.gr. = 1.14)

or R = 300 yds/lb. polypropylene (sp.gr. = 0.91)

or R = 212 yds/lb. manilla (sp.gr. = 1.29)

In the total text system then the formula is inverted to become:

$$\frac{d_2}{d_1} = \frac{(\rho_1 \text{ Tex } 2)1/2}{(\rho_2 \text{ Tex } 1)}$$

If the new net were to be made in manilla, then to allow for twine adequately strong (150 or 110 yds/lb) the net size would have to be reduced. This is undesirable. The same size of net could be used if made in nylon or polypropylene twine.

Comparison of trawl resistance

A standard Granton trawl made in 240 yd/lb nylon would have the correct resistance. Let the estimated resistance of the proposed trawl (Fig.9) be compared with that. If slightly increased resistance due to increased headline height is for the moment ignored the resistance of the nets can be compared according to the formula.

Drag Ratio = Area Factor x Mesh Factor x Twine Factor

$$\frac{D_m}{D_s} = \left[\frac{M_m\ N_m}{M_s\ N_s}\right]^2 \times \frac{M_s}{M_m} \times \left[\frac{P_s\ R_s}{P_m\ R_m}\right]^{\frac{1}{2}}$$

Where D = drag
M = meshsize
N = number of meshes round the mouth
P = specific gravity of twine
R = Runnage of twine
suffix "s" denotes the standard set of conditions
suffix "m" denotes the modified set of conditions

$$\frac{D_m}{D_s} = \left[\frac{(200\times5\frac{1}{8}) + (270\times3.85}{2\times200\times5\frac{1}{2}}\right]^2 \times \frac{5\frac{1}{2}\times2}{(5\frac{1}{8}+3.85)} \times \left[\frac{240\times2}{200+300}\right]^{\frac{1}{2}}$$

$$= 0.88 \times 1.23 \times 0.98$$

$D_m = 1.06\ D_s$ where Ds refers to the drag of the standard Granton trawl made in 240 yds/lb nylon.

Although strictly this formula should only be used to compare the drag of the nets made the same shape (i.e. scaled up or down in linear dimensions) and towed at the same fishing shape (i.e. with scaled flotation and spreading forces) it can be used in this way when the nets are not very different in shape. It indicates that the drag of the proposed trawl will have just about the correct resistance and therefore be correctly spread by the chosen otter boards. Any further calculation of trawl drag first requires a calculation of what the trawl spread will be.

Calculation of net spread and lead-in angle

The catenary has been found to be a useful approximation to the shape of a trawl headline and groundrope giving their spread and lead-in angle at the wing tips. This remains true despite the argument that local distortion near the quarters causes a significant departure from catenary shape. It can be argued on the contrary that this local distortion at the quarters is a mark of indifferent net design and that the webbing cut should rather be tailored to conform more closely to the catenary shape.

Catenary formulae

$$\cosh^{-1} y = \log_e \left\{ y \pm \sqrt{y^2+1} \right\}$$

$$x = a \sinh^{-1} s/a$$

$$y = a \cosh x/a = \sqrt{a^2+s^2}$$

$$s = a \sinh x/a$$

$$T = wy = w(a+d)$$

$$\psi = \tan^{-1} s/a$$

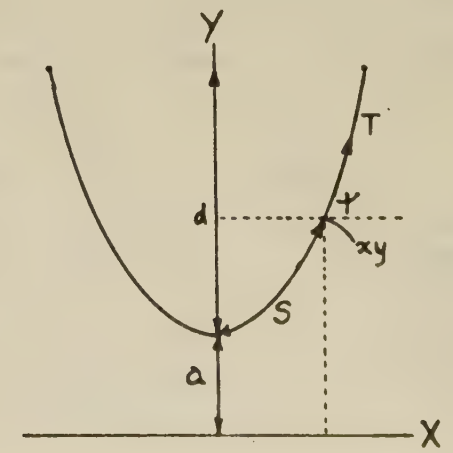


Fig. 5 Catenary

Catenary formulae applied to headline and groundrope spread

Let S be the semi-rope length, and L be the semi-spread, then a factor f = L/S gives the proportion of the rope length to which the rope is spread.

so $S = a \sinh L/a$ becomes $S = a \sinh f\ S/a$

or $S/a = \sinh f\ S/a$

For a range of values of f from 0.4 to 0.8 which covers the range encountered in trawling practice, solutions of the above can be found. The equations can be solved graphically as follows:

When f = 0.4			
S/a	5	6	7
f S/a	2	2.4	2.8
sinh f S/a	3.63	5.47	8.19

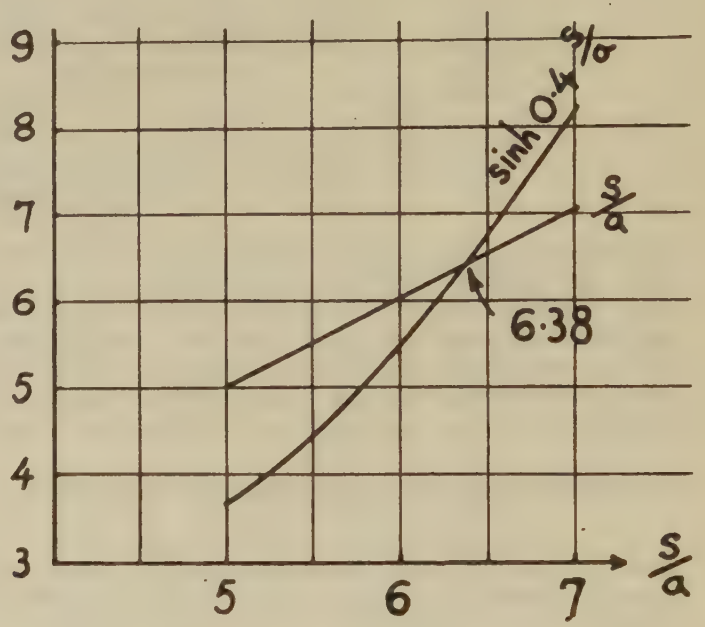


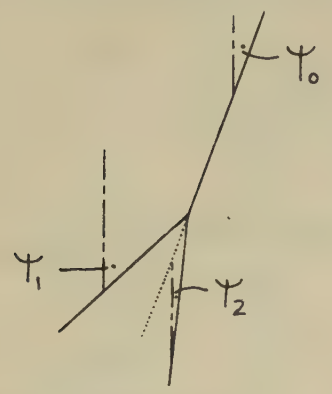
Fig. 6 Graphical solution

giving the solution S/a = sinh 0.4 S/a when S/a = 6.38, and so on for the other cases.

Table and graph relating, Spread, lead-in Angle and Dip.

=	L/S	0.4	0.5	0.6	0.7	0.7
	S/a	6.38	4.35	3.07	2.17	1.47
$\tan^{-1}$	S/a	81.1°	77.1°	72.0°	65.3°	55.8°
lead in angle	↓	8.9°	12.9°	18.0°	24.7°	34.2°
$\frac{d}{2a}$		0.426	0.399	0.363	0.321	0.265

Relating otter board spread to net spread and lead-in angle

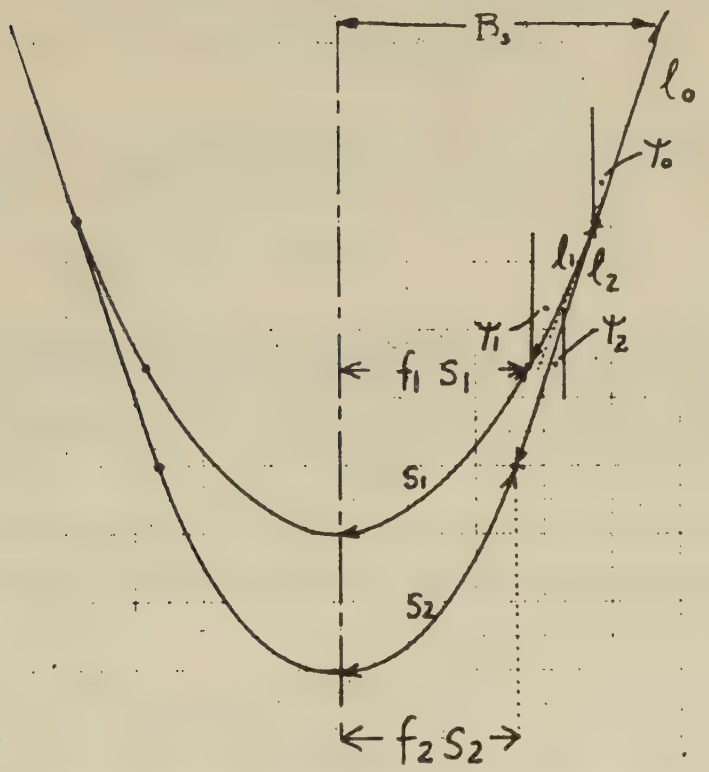


$$\psi_o = \psi_1 - k\,(\psi_1 - \psi_2)$$

where K is dependent on the relative tensions in upper and lower spreading wires

also

$$f_1 S_1 + l_1 \sin\psi_1 = f_2 S_2 + l_2 \sin\psi_2 = B_s - l_o \sin\psi_o$$



$$f_1 s_1 + l_1 \sin\gamma_1 = f_2 s_2 + l_2 \sin\gamma_2 = Bs - l_o \sin\gamma_o$$

Fig. 7 Catenary shape of trawl headline and groundrope

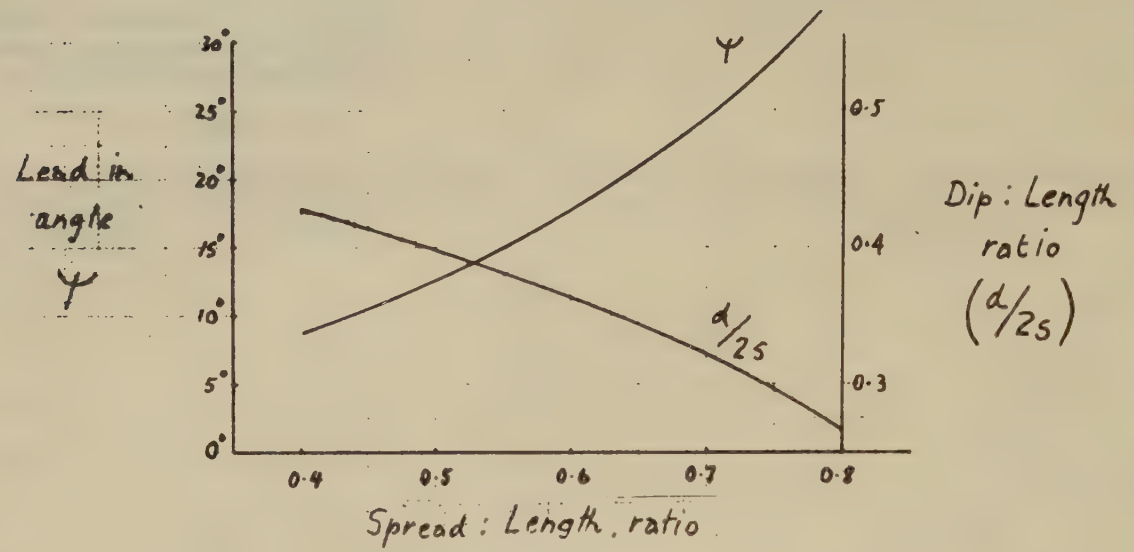


Fig. 8 Catenary, spread, lead in angle and dip

The whole or only part of the groundrope may be taken as a catenary. The end parts of it may be assumed to be straight. μ is the proportion of the semi-groundrope length assumed to be straight. Heavy bobbins at the centre of the groundrope increase the value of μ, while a large area of lower wing netting will decrease it. Values normally range from $\mu = 0$ to $\mu = 0.5$

Inserting values for the proposed net into these equations gives:

Assume end 16 ft of groundrope is straight i.e. $\mu = \frac{16}{58} = 0.276$

Headline = 85 ft $\therefore S_1 = 42.5$ ft

Groundrope = 116 ft of which end 16 ft is straight $\therefore S_2 = 42$ ft

Spreading wires = 60 ft $\therefore \ell_1 = 60 + 16 = 76$ ft

Assume that because of three wire system ϕ_0 bisects ϕ_1 and ϕ_2

Since trawl drag and otter board spreading forces are maintained at the same ratio as with the Standard Granton trawl it follows that the sweep angle will be the same, say 18°

$\therefore \phi_0 = 18° = \phi_1 - \frac{1}{2}(\phi_1 - \phi_2)$

Conditions at the end of the spreading wires

$f_1 S_1 + \ell_1 \sin \phi_1 = f_2 S_2 + \ell_2 \sin \phi_2$

Using Fig. 8 and by successive approximations the equation can be balanced as below:

$$0.622 \times 42.5 + 60 \sin 19.25^\circ \doteqdot 0.58 \times 42 + 76 \sin 16.75^\circ$$

$$24.4 \text{ ft} + 19.8 \text{ ft} \doteqdot 24.4 \text{ ft} + 21.9 \text{ ft}$$

$$46.2 \text{ ft} \doteqdot 46.3 \text{ ft}$$

hence spread between spreading wire swivels = 92.5 ft

Headline spread = 52.8 ft

Groundrope spread = 48.8 + 32 sin 16.75° = 58.0 ft

Check on square length

Using the dip curve of Fig. 8 it is possible to check that the length of the fishing square is adequate for the overhang between headline and groundrope.

at f_2 = 0.58, Groundrope dip = 0.371 x 84 + 16 cos 16.75° = 46.5 ft

at f_1 = 0.622, Headline dip = 0.355 x 85 x 85 = 30.1 ft

∴ overhang = 16.4 ft

The spread of the square including its curvature $\doteqdot$ headline spread

∴ Setting angle of the meshes Φ is given by

$$\sin \Phi = \frac{52.8 \times 12}{340 \times 3.85} = 0.485$$

Another way of finding the setting angle at least in the middle of the square is by the number of meshes hung on the headline bosom (17')

here $$\sin \Phi = \frac{17 \times 12}{81 \times 5.12}$$

$$= 0.49$$

which is in good agreement with the previous figure of 0.485

$\sin \Phi = 0.49$ $\Phi = 29^\circ 20'$

$\cos \Phi = 0.872$

$$\text{length of square required} = \frac{\text{overhang}}{\cos \Phi} = \frac{16.4}{0.872}$$

$$= 18.8 \text{ ft}$$

On this basis the square is short by 0.8 ft or 4½% but the agreement is as good as is to be found in most trawls. Note that the required length of square will alter as the headline spread alters, a longer square being required with a bigger spread. It is for this reason that the square tends to split when otter boards that are too big are used and tends to bag when the net is used with otter boards that are too small.

A series of calculations could be run to set limits on the board sizes which would cause distortion one way or the other.

Net drag

Having now obtained the net spread the trawl resistance may be calculated from scratch. This approach to the estimation of trawl drag from basic design data should be treated with some caution as it is still in the experimental stage. It is however a useful approach along commonsense empirical lines that the drag must be largely determined by the area of netting in the different parts of the net, the relationship between twine diameter and meshsize in the different parts and the extent to which the mouth of the net is opened.

Total net drag can be estimated from the equation (Dickson and Foster 1963) (Foster 1965):

$$Dn = S\frac{d}{a}\frac{1}{125}\left(\frac{1 + 6.6 \times 2Y_g \times H}{S}\right)$$

where Dn = total net drag

S = total surface area of netting

$\frac{d}{a}$ = ratio of twine diam/bar length

2Yg = groundrope spread at the wing ends

H = headline height at centre

Total surface area S

Component	2a	n	mean width 2an/24	length	area sq. ft. at Φ = 45°	
1 upper wing	5.125	73.5	15.7	34	535	
1 end piece	"	36	7.7	7.7	60	
2 upper wing					595	1190
1 lower wing	5.125	29	6.2	53.5	332	
2 lower wing						664
Square	3.85	305	48.8	18	880	880
Batings	3.85	195	31.3	36.2	1030	
	2.56	150	16.0	9.6	154	1184

Belly	5.125	175	37.4	19.2	718	
	3.85	160	25.6	19.2	490	
	2.56	150	16.0	9.6	154	1362
Extension pieces	2.56.	90	9.6	9.6	92	184
Codend	2.56	60	6.4	18.0	115	230
						5694

Note - Mean width and length are reduced or "set in by the half" and fully extended respectively.

The following formula may be used to obtain the diameter of nylon twine.

$$d = \sqrt{\frac{1.33}{R}}$$

where d = diam in in.

R = runnage yd/lb

Component	2a	R	d	$\frac{d}{a}$	ΔS	$\Delta S\frac{d}{a}$
Upper wings	5.125	300	.0665	0.026	1070	27.8
Upper wing end pieces	5.125	$\frac{300}{2}$	.094	0.0367	120	4.3
Lower wings and first sheet of belly	5.125	200	.082	0.032	664 718	44.2
Square	3.85	300	.0665	0.0345	880	
Batings 1st Sheet	"	"			1030	82.8
Belly 2nd Sheet	"	"			490	
Batings 2nd Sheet	2.56	"	"	0.052	154	16.0
Belly 3rd Sheet	"	"			"	

Extension pieces	2.56	200	.082	0.064	184	11.8
Codend	2.56	$\frac{300}{2}$	.094	0.0735	230	16.9
	Total	$\frac{Sd}{a}$	=	$\sum_{\Delta} \frac{Sd}{a}$		203.8

$$Dn = 203.8 \frac{1}{125} \left\{ 1 + \frac{6.6 \times 58 \times 9}{5694} \right\}$$

$$= 1.63 \ (1 + 0.605) = 2.62 \text{ tons}$$

This is the estimated drag of the net alone, to which must be added the drag of floats, bobbins, sweep wires, otter boards and warps to give the total drag of the gear.

The drag of net appendages, groundropes and ground friction and headline floats was previously estimated at 0.4 ton.

Thus estimated drag of net plus appendages = 2.62 + 0.4 = 3.02 ton

Hydrodynamic drag of otter board = $2.87 C_D A V^2$ where V is in knots

$= 2.87 \times 0.64 \times 28.2 \times 3.5^2$ lb

= 0.28 ton

Friction drag of otter board = μ_F (ground reaction) where μ_F = ground friction

$$= \mu_F \left\{ \frac{\text{wt. of board in water}}{3} \right\}$$

$$= 0.4 \left(\frac{300}{3} \right)^3 = 0.04 \text{ ton}$$

∴ drag of otter board = 0.28 + 0.04 = 0.32 ton

drag of gear otter boards = 3.02 + 2 (0.32) = 3.66 ton

Add to this a further 10% for the drag of the warps and the drag of the whole gear at the ship may be estimated at 4.1 tons.

Onto Fig. 3 are plotted the estimated resistance line of the Granton trawl previously used and the estimated resistance of the trawl which has been under discussion. The instruments available for measuring trawl drag and speed were very limited but the few values actually obtained during fishing operations are plotted on the graph. It appears in fact that the estimate of trawl drag is rather better than the estimate of available propeller thrust.

Little more warp pull or towing speed was obtained by an increase in propeller speed from 320 to 340 rpm only the propeller wake appeared more turbulent.

It has already been mentioned (p.9) that hull drag at trawling speed has not been deducted from the thrust available for towing and for a ship of this length, beam and propeller diameter a thrust deduction factor of perhaps about 5% should also be deducted because the thrust curves derived from Troost are for propellers in open water rather than behind a ship (Harvald 1963).

Both these considerations would reduce the thrust available for towing below that shown in Fig. 3. On the other hand it can also be deduced from Harvald's paper that the wake fraction of 0.2 as used in these calculations is rather too low and a higher value of 0.27 would pull the available thrust curves up again. There has not yet been enough research work done to know for sure what thrust deduction factor and what wake fraction to use under trawling conditions. This is a matter requiring further measurement and study after which some refinement can be applied to the method of matching trawl resistance to towing power that has been outlined here.

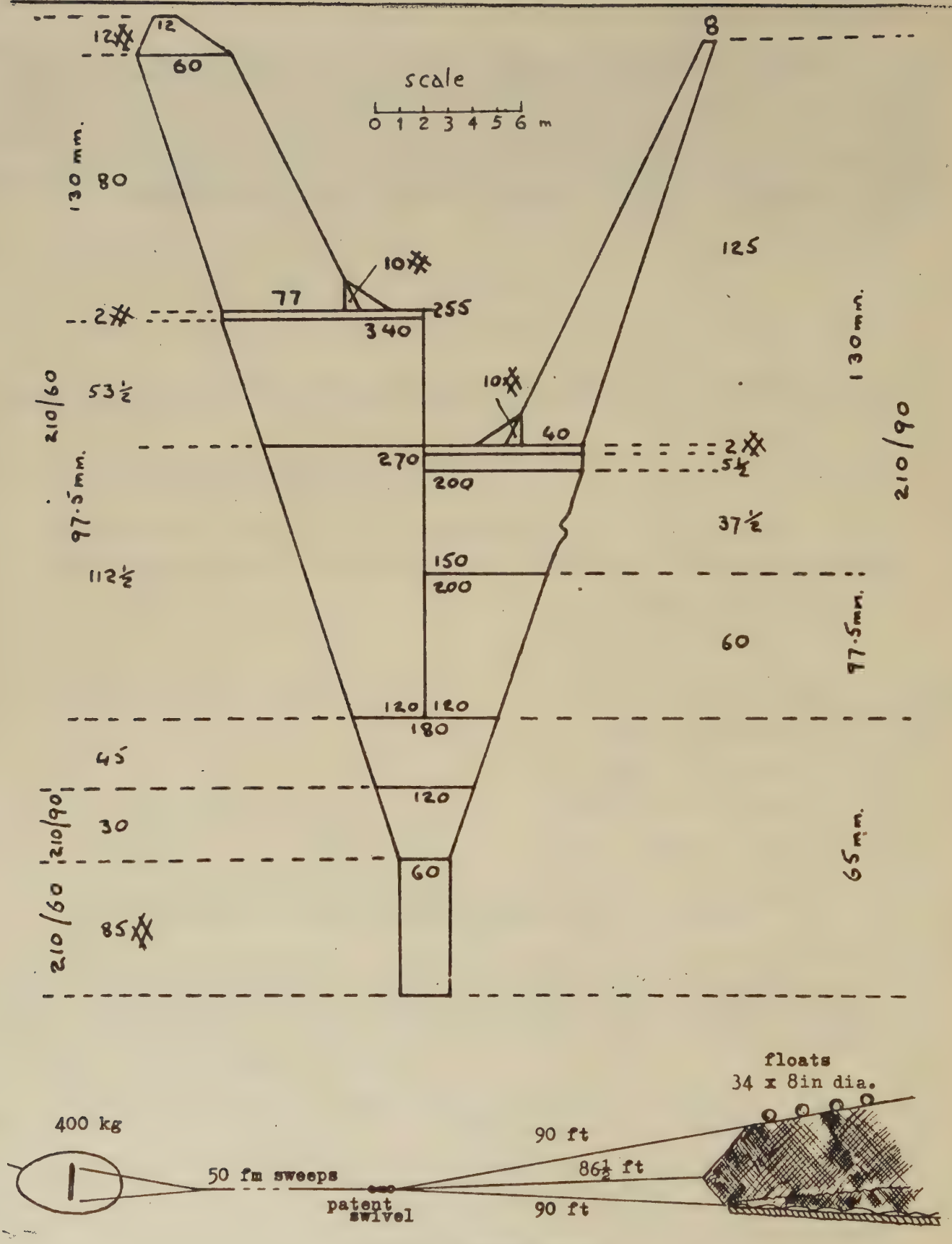


Fig. 9 Gandara trawl

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